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Ionospheric regional forecasting using statistical method for GPS application

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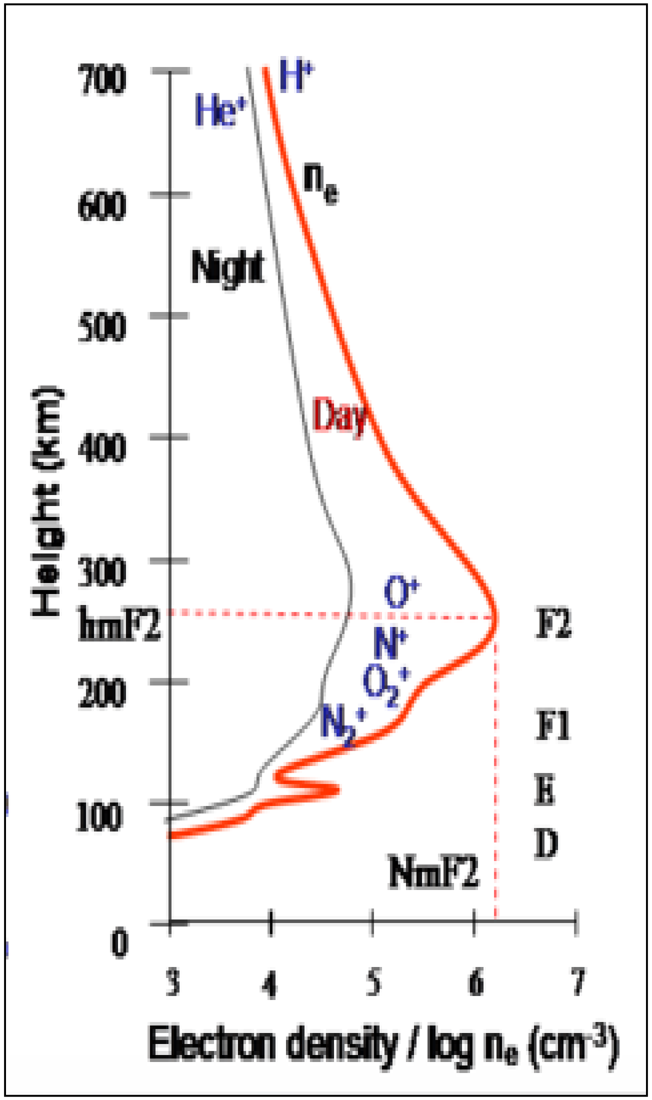
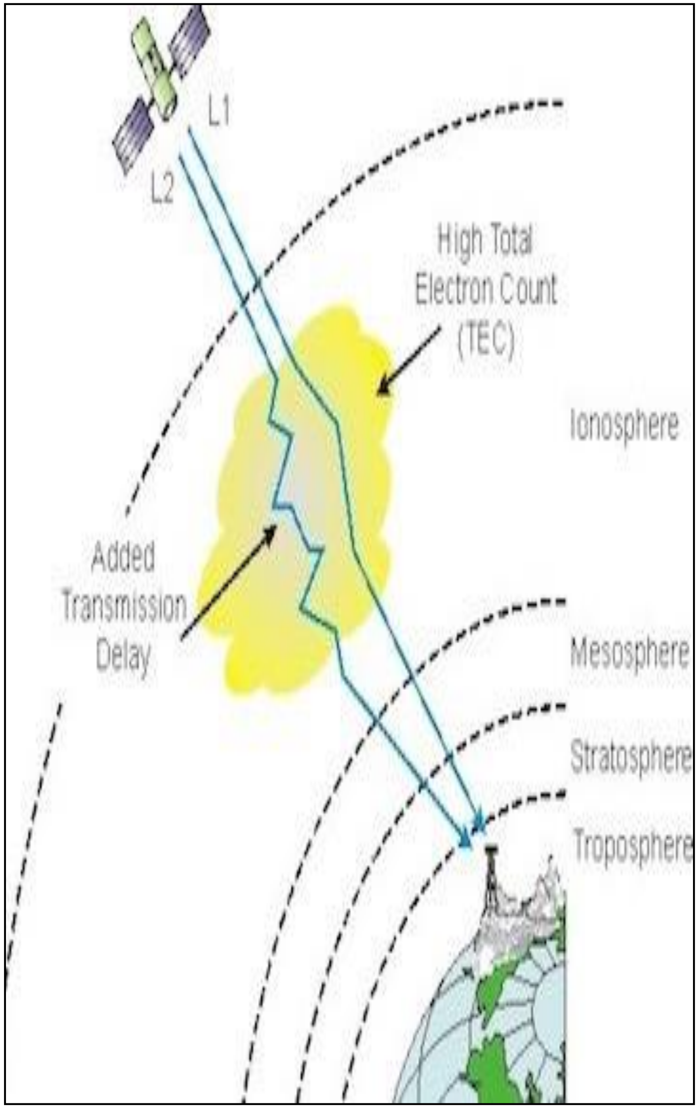
Introduction

- The ionosphere is a shell of electrons and electrically charged atoms and molecules that surround the Earth, stretching from a height of about 50 km to more than 1,000 km.
- The ionosphere varies to several factors such as diurnal variation, seasonal variation, solar cycle, geomagnetic effect, etc.→ geographical location
- The propagation of radio signals in the Earth's atmosphere is dominantly affected by the ionosphere due to its dispersive nature.
- Global positioning system (GPS) data provides relevant information that leads to the derivation of total electron content (TEC).
- The TEC is one of the most important parameters that describe the ionospheric state & structure.



Motivation

- Ionosphere is the main error source for the GPS signal
- Klobuchar model can only reduce 50% of the ionospheric error
- The study of the ionospheric delay forecasting is beneficial to improve and develop the ionospheric models.
- It is important to select the suitable prediction model that can correct the ionospheric delay errors to further improve the accuracy performance of GPS positioning



Objective

1. To analyse the short-term forecasting ionospheric delay using statistical Holt-Winter method
2. To compare Holt-Winter method with IRI-2012

Methodology

- GPS Ionospheric Scintillation and TEC Monitor (GISTM), model GSV4004B by GPS Silicon Valley
- NovAtel Euro-3M dual-freq. receiver
- Measure amplitude and phase scintillation from the L1 frequency GPS signals
- TEC from the L1 and L2 frequency GPS signals.

1.	NovAtel GSV 4004B GPS receiver
2 .	GPS Antenna
3,4,5,6.	Connection cable (30 m maximum)
7.	PC processing data,
8.	UPS

TEC = [9.483 * (PRL2 – PRL1 - C/A-P,PRN) + TECRX + TECCAL] TECU

PRL2 is the L2 pseudo-range in meters , PRL1 is the L1 pseudo-range in meters , C/A-P,PRN is the input bias between SV C/A- and P-code code chip transitions in meters , TECRX is the TEC result due to internal receiver L1/L2 delay , TECCAL is the user defined TEC offset

- GISTM provide slant TEC that can be converted to Vertical TEC

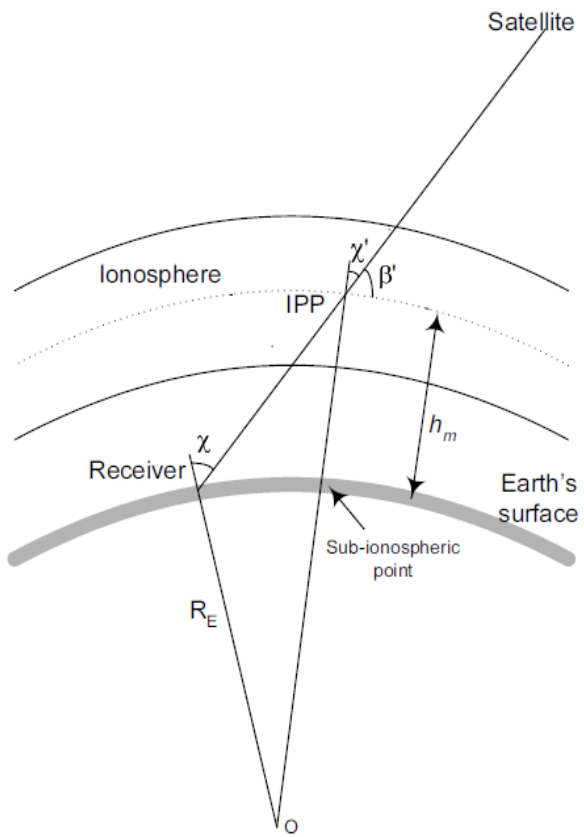
$$VTEC = STEC\cos\chi'$$

- Delay between the L1 and L2 signal

$$I_k^p = 40.3\mathrm{VTEC}\left(\frac{1}{f_2^2} - \frac{1}{f_1^2}\right)$$

- Percentage deviation between the model and GPS-TEC

$$\%PD = \frac{VTEC_{\text{model}} - VTEC_{\text{GPS-TEC}}}{VTEC_{\text{GPS-TEC}}} \times 100$$



Ref: Abdullah M. 2004. Modelling and determination of ionospheric effects on relative GPS measurements, PhD thesis, Leeds University, UK and other references herein.

- **Holt-winter** is statistical method that can be used to forecast the ionospheric delay, producing short-term forecasting by employing level, trend and seasonal components at each period of the time-series.
- $F_{t+m} = (L_t + b_t m) S_{t-s+m}$

L_t, is the level; b_t, is the trend; S_t, is the seasonal; Y_t, is the VTEC, while t is the time period for the component of L_t,b_t, S_t and Y_t. F_t, is the forecasting value of a period ahead; F_{t+m}, is the forecasting time period. m, is the forecast period and s is the seasonal duration.

- Mean Absolute Percentage Error (MAPE) to measure the suitability and accuracy of a forecasting method

$$PE_t = \left(\frac{Y_t - F_t}{Y_t} \right) \times 100 \qquad \text{MAPE} = \frac{1}{n} \sum_{t=1}^{n} |PE_t|$$

PE is the percentage of error, Y_t, is the VTEC

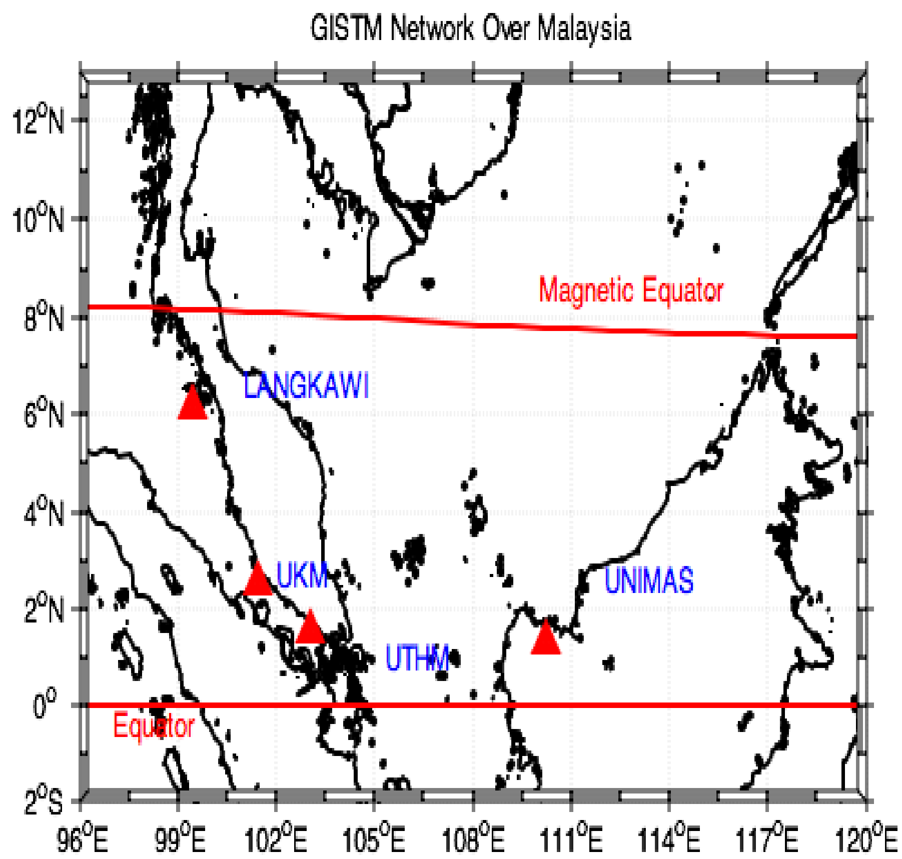
Ref:. Suwantragul, S., Rakariyatham, P., Komolmis, T. and Sang-In, A., 2003. A modeling of ionospheric delay over Chiang Mai Province. *Proc IEEE Int Symp Circuits Syst*. 25(2), 340-343.

Elmunim, N. A., M. Abdullah, A. M. Hasbi, and S. A. Bahari. 2016. Comparison of GPS TEC variations with Holt-Winter method and IRI-2012 over Langkawi, Malaysia. *Advances in Space Research* . http://dx.doi.org/10.1016/j.asr.2016.07.025

Elmunim, N.A., Abdullah, M., Hasbi, A.M., Bahari, S.A., 2015. The comparison of statistical Holt-Winter models for forecasting the ionospheric delay using GPS observation. *Indian Journal of Radio and Space Physics*. 44, 28-34.

Data processing

- Use GISTM data located at:
  - **Langkawi (6.19°N, 99.51°E)**
  - **UKM, Bangi (2.92° N, 101.78°)**
- Period:
  - **January to December 2011, 2014**



Results

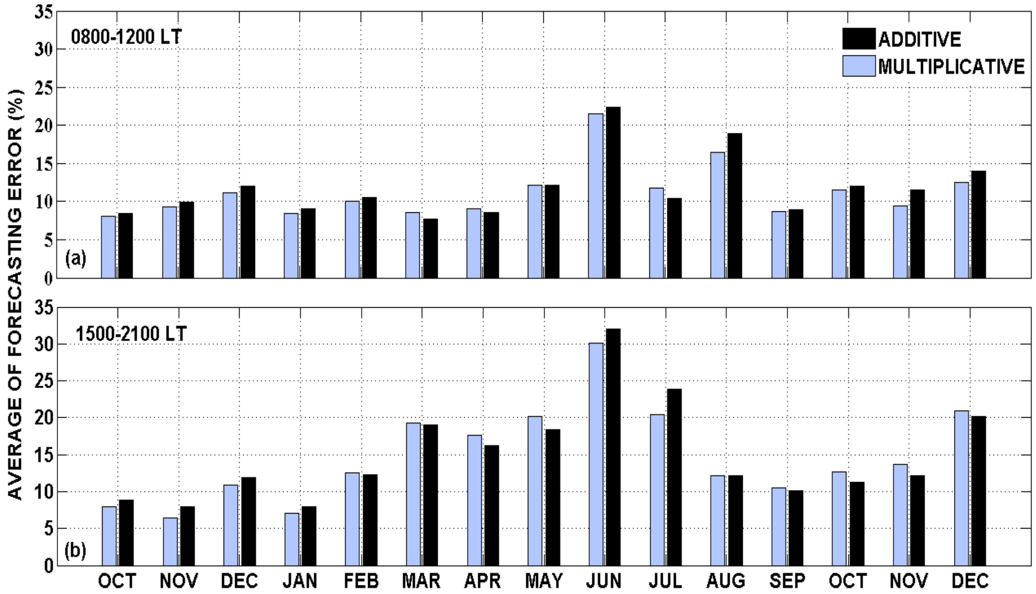
Comparison of

1. GPS TEC variations with Holt-Winter method and
2. With IRI-2012

- Diurnal
- Monthly
- Seasonal

Holt-Winter: Multiplicative and Addictive

Average of forecast error obtained from Oct 2009 to Dec 2010 in addictive and multiplicative model

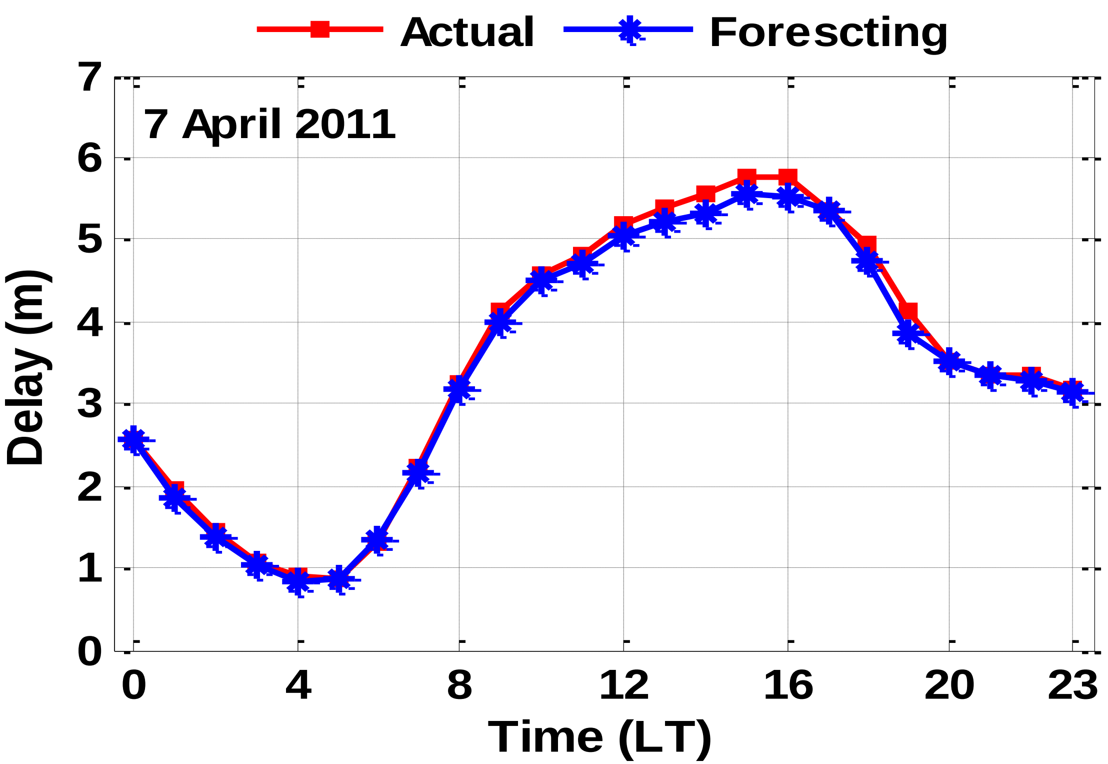


Multiplicative model forecast better by 2% (0.05m) than of Additive model

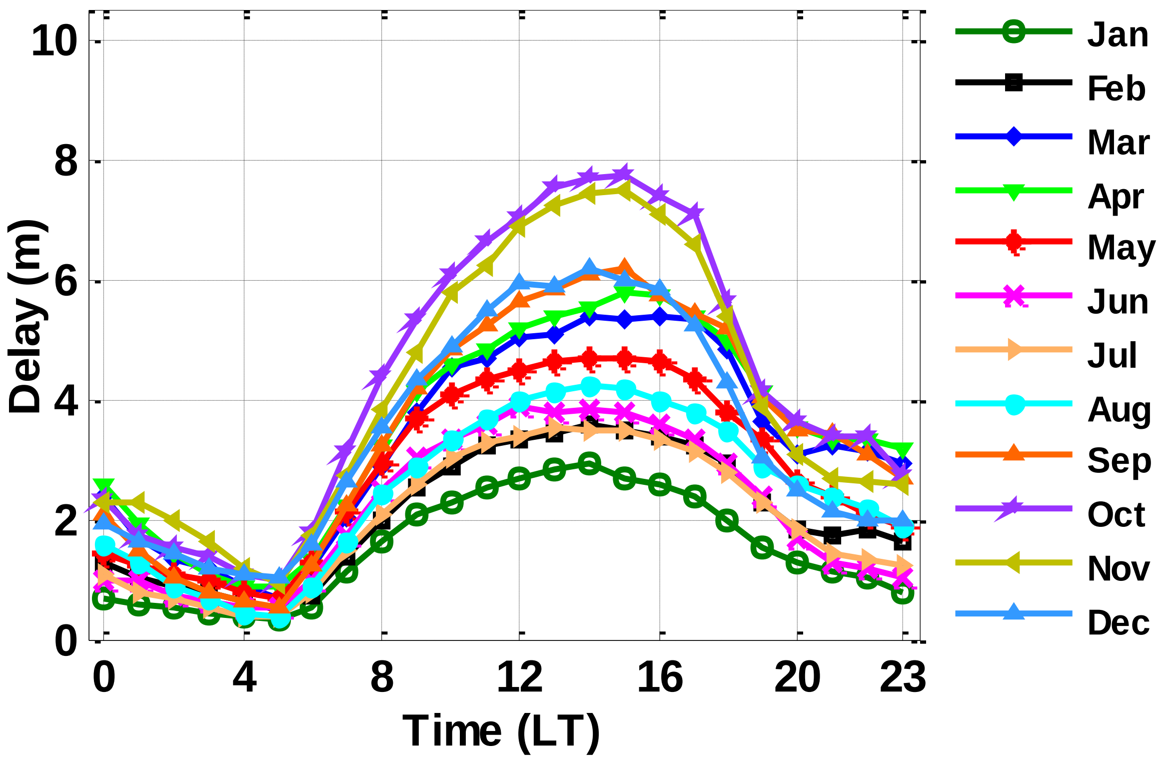
Elmunim,NA, Abdullah, M, Hasbi, AM &Bahari, SA,, 2015, Comparison of statistical Holt-Winter models for forecasting the ionospheric delay using GPS observations, *Indian Journal of Radio & Space Physics* 44:28-34

Results : GPS TEC variations with Holt-Winter method

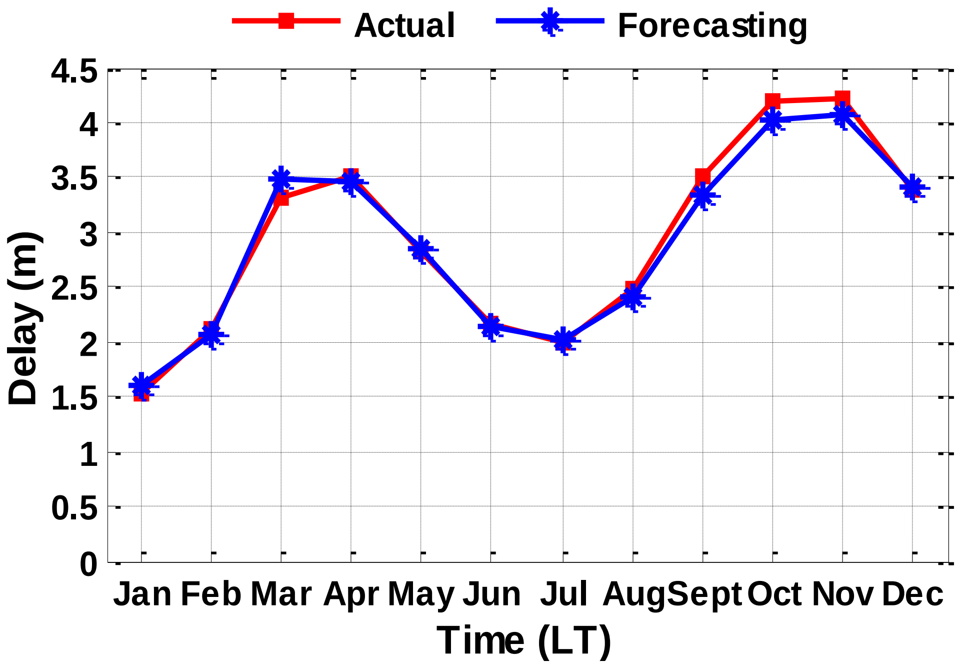
Diurnal variation of the actual and forecast ionospheric delay using the Holt-Winter method over UKM station during 7 April 2011



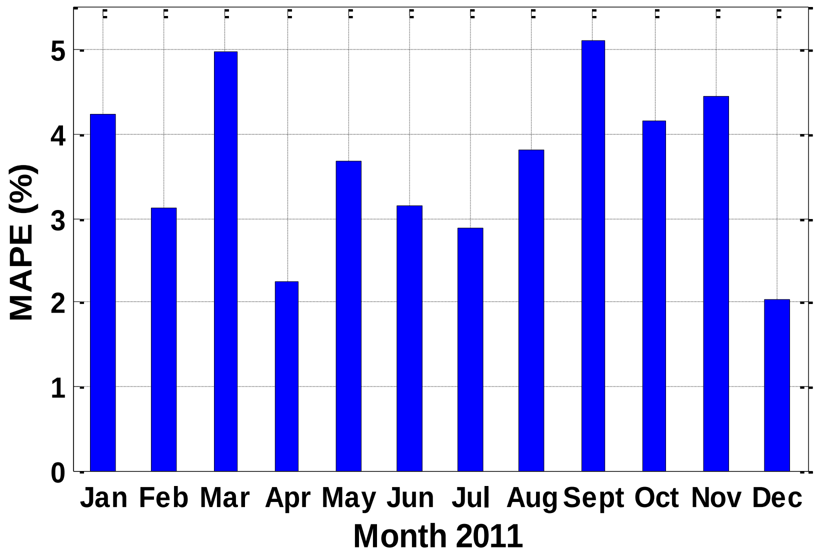
The monthly variation of the actual ionospheric delay over UKM station during 2011



Month to month variation of the actual and forecast ionospheric delay using the Holt-Winter method

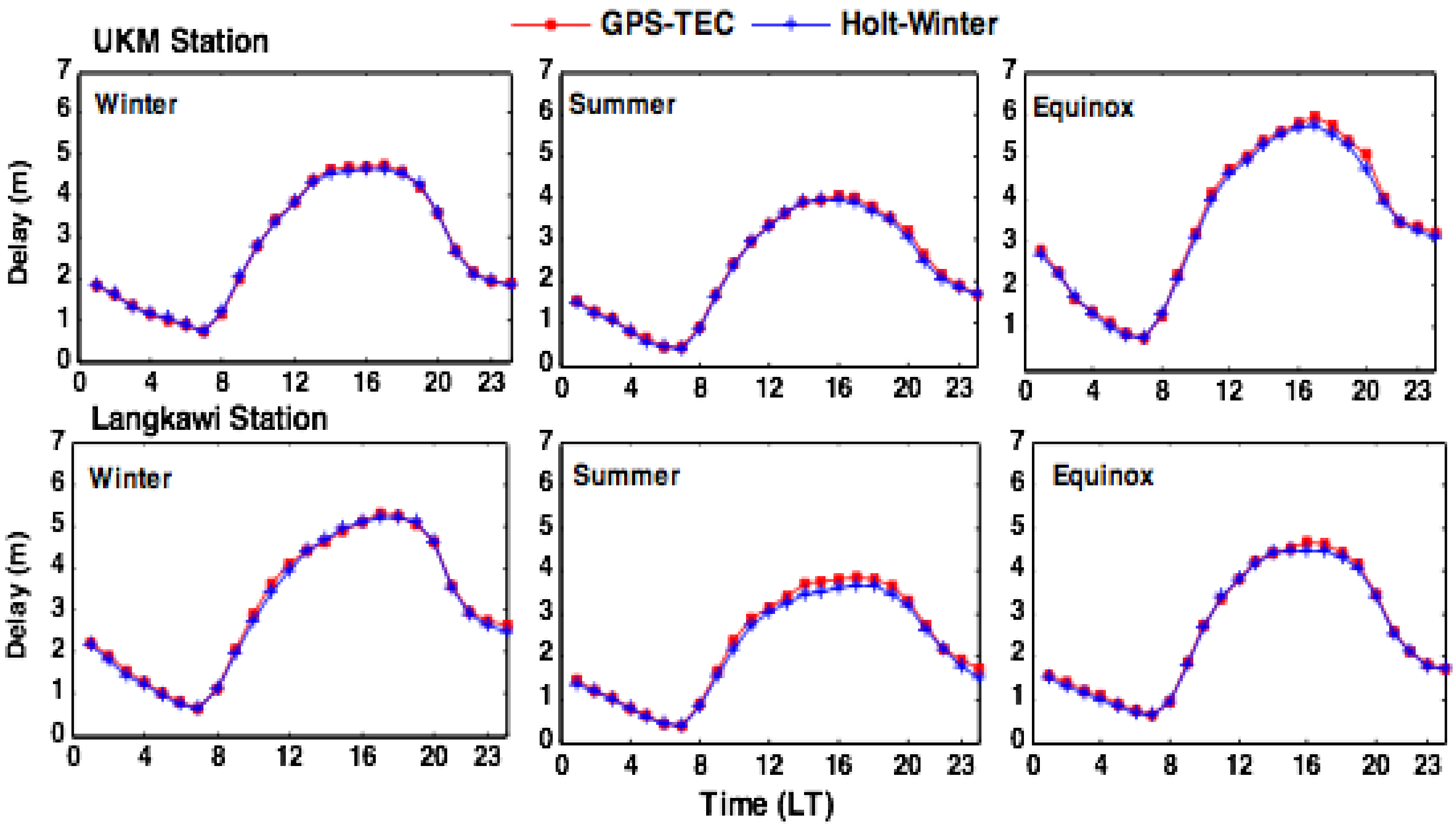


Variability of the error measurement MAPE

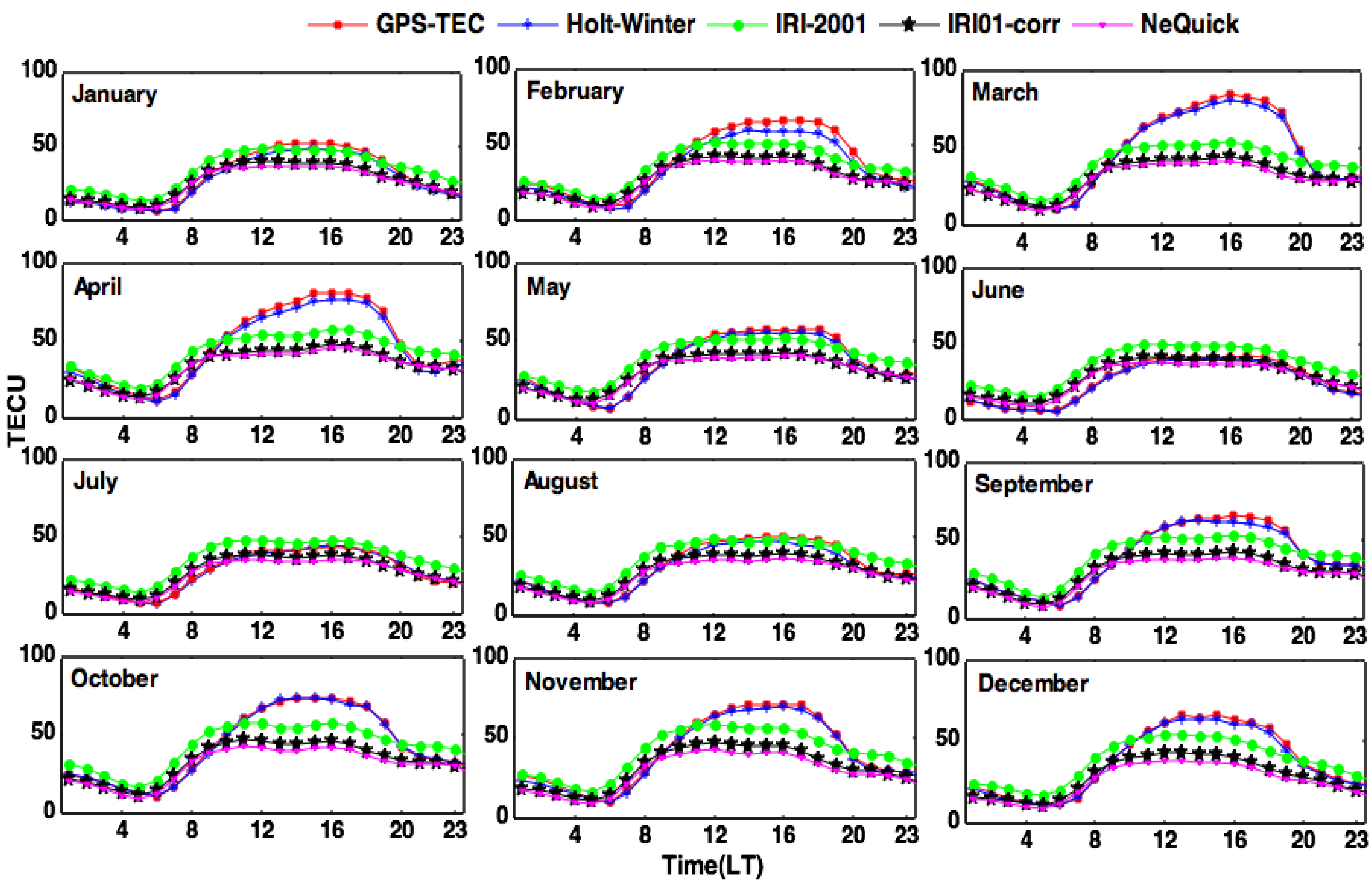


Seasonal variation over UKM and Langkawi station -2011

- Winter (January, February, November, December)
- Summer (May, June, July, August)
- Equinox (March, April, September, October)

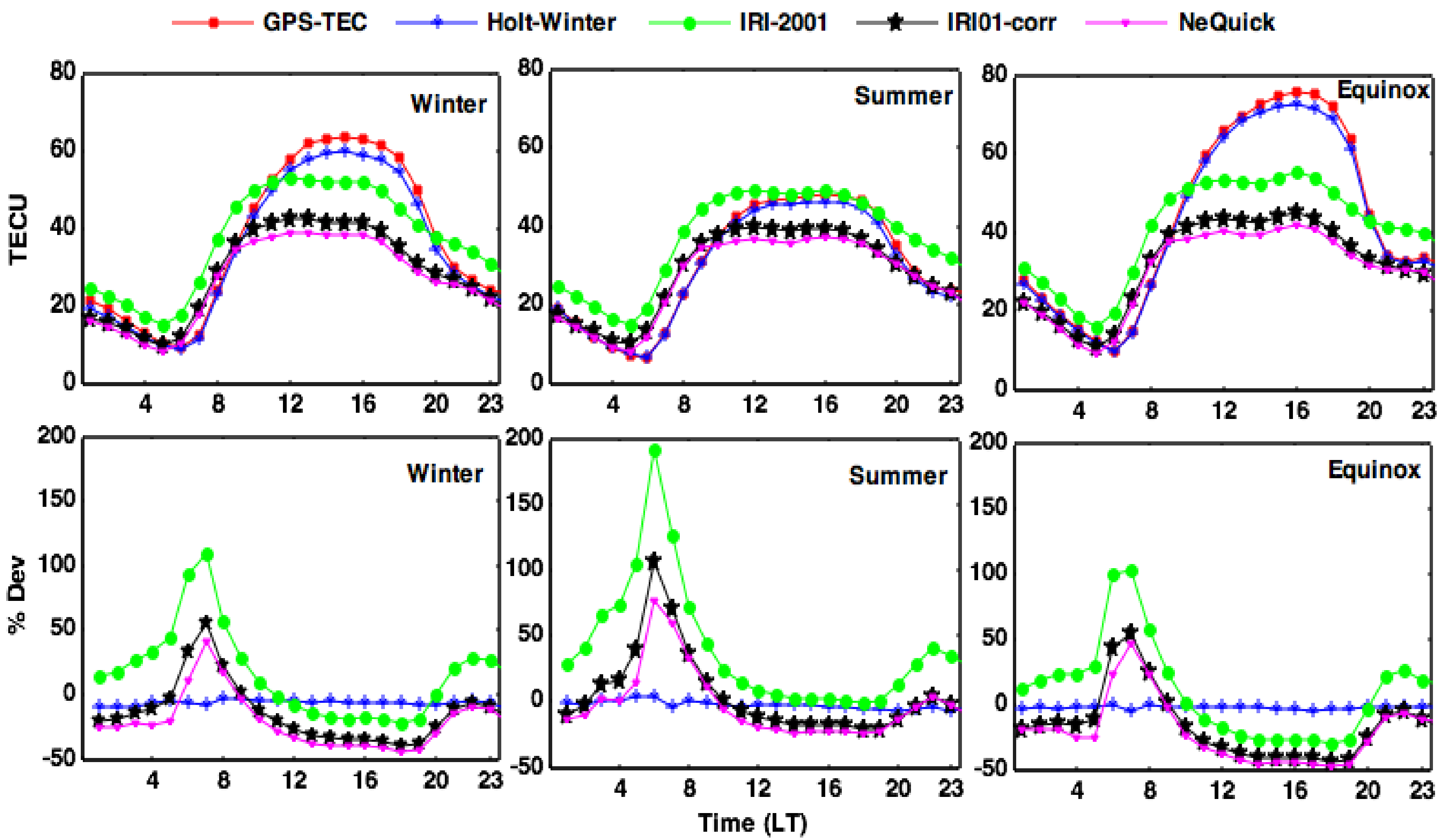


Results : GPS TEC variations with Holt-Winter method and IRI-2012

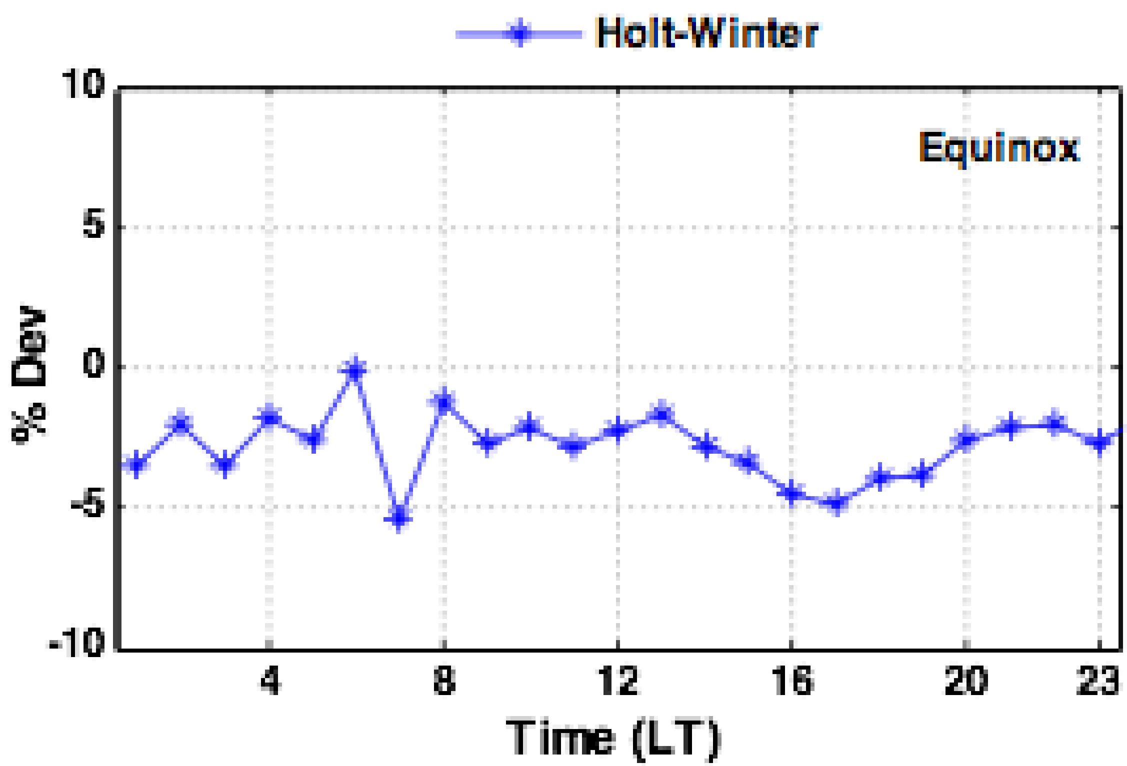


Comparison of the Holt-Winter method with IRI-2012 over Langkawi station in 2014

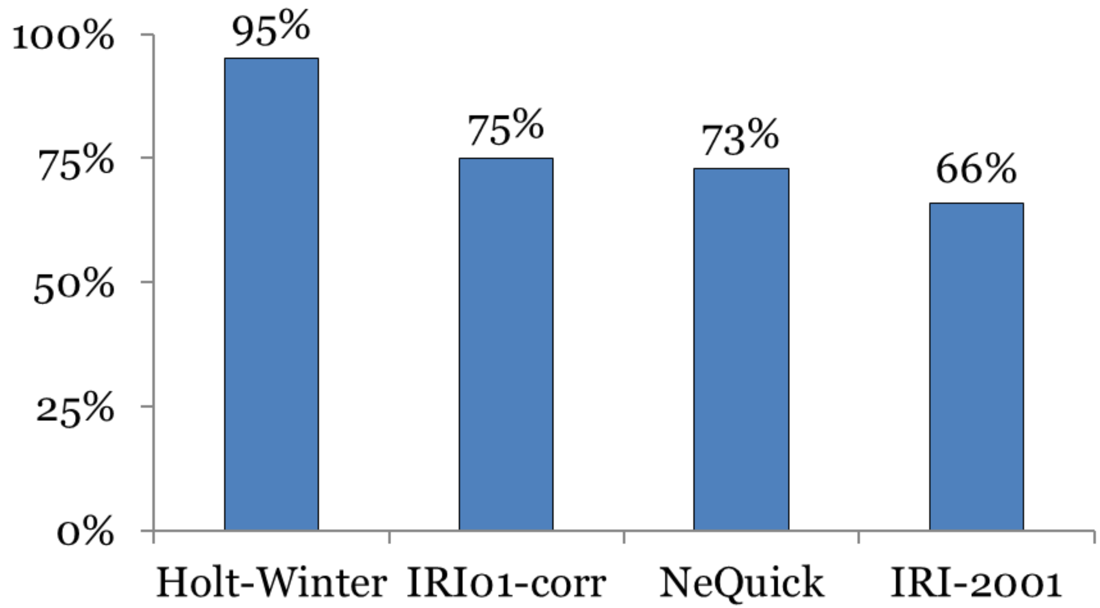
Comparison of the seasonal VTEC from GPS-TEC with IRI-2012 topside options and Holt-Winter method and their %Dev



Closer inspection to illustrate the %Dev of the Holt-Winter method



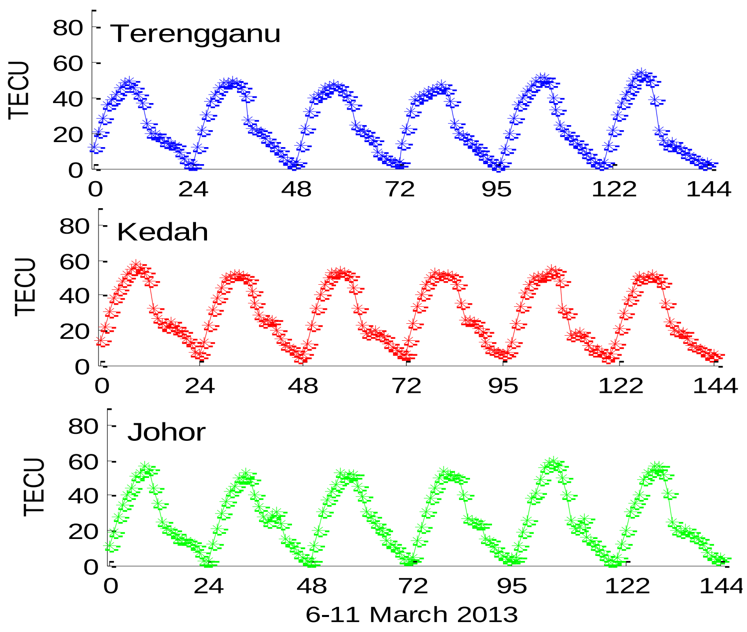
Accuracy of prediction model



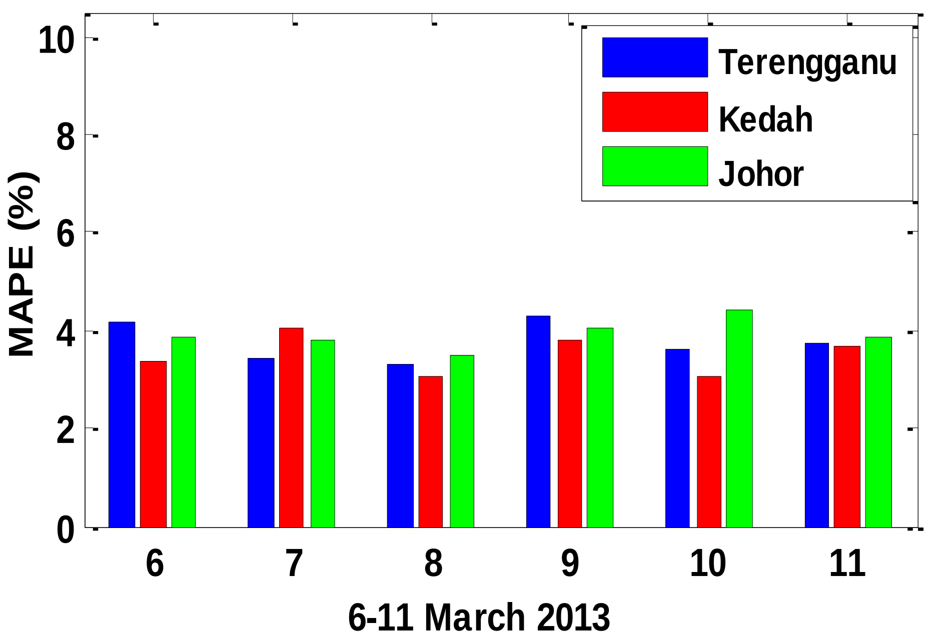
- That can be conclude that the Holt-Winter method indicates high performance and better estimate of the VTEC prediction

Forecasting the GPS TEC in different stations over Malaysia Terengganu(4.62°N-103.21°E), Kedah (6.46°N-100.50°E) and Johor (1.36°N-104.10°E).

Variation of the GPS TEC forecasting



Variability of the error measurement MAPE



Conclusion

- Holt-Winter can be used to forecast ionospheric delay and show higher accuracy compare to the IRI-2012
- Holt-Winter shows a good forecasting result in different stations over Malaysia
- Help to mitigate ionospheric error in GPS positioning for better accuracy

IconSpace 2017 3-5 May 2017 in Kuala Lumpur

Publications:

1. **Book Chapter Published by Springer**
2. **Journal of Physics: Conference Series (JPCS) by IOP**
3. **Special Issue (SI) on *Space Science for Sustainability***
   Journal of Atmospheric and Solar-Terrestrial Physics (JASTP)
4. **Abstracts Only**

Thank you